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BULLETIN UNIVERSITY OF NEW MEXICO

WHOLE NO. 51

Geological Series Vol. III., No. 1

Geology of the Vicinity of Albuquerque

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ALBUQUERQUE, NEW MEXICO
JUNE, 1909

Published Quarterly by the University

GEOLOGY

of the Vicinity of Albuquerque

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INTRODUCTION

The city of Albuquerque is situated in the north-central part of the Territory of New Mexico, in the valley of the Rio Grande. This paper treats of the geology of an area eleven miles by twelve with the city as a center.

Albuquerque is the chief city of the Territory and is the junction point of the Atchison, Topeka & Santa Fe and the Santa Fe coast lines. The New Mexico Central, under construction, enters the area from the east, through the Menaul School arroyo and has its terminal at Albuquerque.

The Rio Grande, carrying great amounts of sand and silt, flows through the middle of the area from north to south and supplies water for irrigation to many acres of land in its immediate valley.

The accompanying map gives the main cultural and geological features. The contours are taken from the U. S. Geological Survey topographical map of Albuquerque Quadrangle. The survey is not accurate as to detail both on account of the large coutour interval and the apparent hastiness of the survey. A few minor corrections have been made by means of an aneroid barometer. This paper was prepared and the field work undertaken as a study of the Tertiary and Quaternary Geology of the valley and presented in partial fulfillment of the requirements for the Bachelors degree in the University of New Mexico. The work has been done under the direction of Dr. W. G. Tight, President of the University, to whom the writer is indebted not only for instruction and training, but for a multitude of facts drawn from his abundant knowledge of New Mexican Geology.

BIBLIOGRAPHY

Cope, E. D. 1874

Notes on Santa Fe Marls and continued Vertebrate Fossils.
Proc. Phil. Acad. Nat. Sci. 1874, pp. 147-152, Pls. ix-xi.

Hayden, F. V. 1867

Prelim. Field Rep. U. S. G. S. of Colorado and New Mexico, pp. 66-68.

Herrick, C. L. 1869

Geology of the Cerrillos & Ortiz Area.
Bull. Univ. of New Mexico, Vol. I.
Geology of Environs of Albuquerque.
Bull. Univ. of New Mexico, Vol. I.
Geology of San Pedro and Albuquerque Districts.
Bull. Univ. of New Mexico, Vol. I.

Herrick-Johnson.

Geology of Albuquerque Sheet.
Bull. Univ. of New Mexico, Vol. II.

Hill, R. T.

Bulletin of the Geol. Soc. of America III, p. 98.

Johnson, D. W.

Geology of the Cerrillos Hills, New Mex.
Reprint School of Mines Quat. Columbia Univ. 1903-4.

Keyes, C. R.

Underground waters of the Jornado del Muerto.
U. S. G. S. Water Supply Paper No. 123.

Marcou, Jules. 1853

Explor. & Survey for R. R. Route from Mississippi Riv. to Pac. Ocean. Vol. III Washington 1856 Pt. IV No. 2, pp. 140-1.

Newberry, J. S. 1808-9

Rep. on Colorado Riv. of the West by Lieut. J. C. Ives, Wash. 1861, Pt. III, pp. 98-9.
Rep. of the Exped. from Santa Fe, N. M. to Junction of Grand & Green Rivers, by Capt. J. N. Macomb, 1809. Geol. Report, pp. 38-42.

Osborn, H. F. and Matthew, W. D.

Cenezoic Mammal Horibons of Western North America.

Reagan, A. B.

Geology of the Jemez-Albuquerque Region Amer. Geol., Vol. XXI No. 2, pp. 67-111.

Stevenson, J. J. 1879

Am. Jour. Sci., Vol. XVIII, pp. 471-5.

U. S. Geol. Survey West 100 Mer., Vol III. Supplement, pp. 159-63.

The work of Dr. C. H. Herrick in Volumes I and II Bull. Univ. of New Mexico has been cited freely in this paper, often without stating either article or page, for his thorough preliminary work in the region makes constant reference a necessity.

PHYSIOGRAPHY

The section of country covered by this paper, as mentioned before, lies in the valley of the Rio Grande. The valley proper is about three or four miles wide, with a gradient of about five feet to the mile. The flat valley floor is largely under ditch, and has been cultivated for centuries.

On either side rise rather steep bluffs, leading to an apparently level upland. To the east the plain, or mesa, rising with a gradually increasing gradient, for about eight or nine miles, to the Sandia Mountains, is known as the Sandia mesa. On the west are two mesas, one rising above the other, like steps, and both dipping slightly to the east. The lower mesa is about one hundred and fifty to two hundred feet above the river, and from three to four miles wide. It is referred to by the natives as "La Loma," since their homes are on the river flood plain and the mesa appears to be a hill. The second mesa lies above the first by about five hundred feet and is bounded on the east by steep bluffs. This is known as "La Ceja del Rio Puerco," since it forms the divide between the Rio Grande and the Rio Puerco. However, in his "Geology of the Albuquerque Sheet," Prof. C. L. Herrick has called this extensive plateau "The Albuquerque Mesa" and thus it will be referred to in this paper.

On the eastern edge of the Albuquerque mesa, is a small group of volcanoes known as "The Albuquerque Volcanos." It consists of three fairly large cones and two smaller ones, lying on a line parallel to the general course of the valley. The

Section of Deep Well belonging to the Water Supply Company of Albuquerque.

Legend.	Thickness.
Sandy clay and sand with gravel	35'
Sandy clay with calcareous cement	5'6"
Gravel and Sand (water bearing)	31'
Cemented sand with seams of silt	4'
Yellow clay	5'
Cemented sand with seams of silt	98'
Coarse sand with some gravel and clay	6'
Calcareous silt, very hard and compact	1'6"
Yellow clay and gravel	4'
Sand partially cemented with some clay	53'
Clay	49'
Fine sand, clayey	28'
Sandy clay	38'
Fine sand, clayey	27'
Compact clay and cemented sand	10'
Fine sand, clayey	45'
Clay	14'
Layers of sand and sandstone, some clay	19'
Fine sand, clayey	14'
Clay, sandy	4'
Fine sand, clayey	7'
Coarse gravel and calcareous clay	11'
Red clay and shale	4'
Clay, layers of sand	22'
Sand with layers of sandstone	26'
Clay	2'
Soft material	9'
Sandstone	42'
Cemented sand	12'
Coarse sandstone	2'
Fine grained hard sandstone	10'
Layers of clay, sand and sandstone	24'
Sandstone	5'
Fine sand	58'(?)

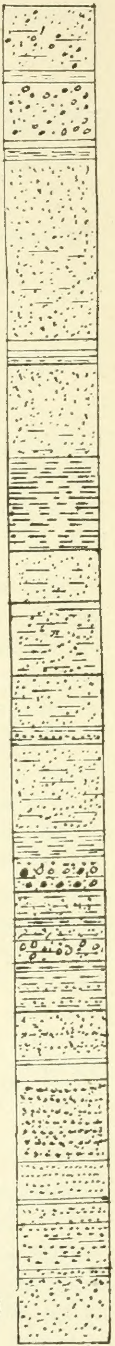

Fig. 1.

The cementing material is always calcium carbonate. The term sandstone is used to distinguish those materials which were hard from the cementing sand which major portion of the lava from these cones flowed out over the Albuquerque mesa toward the east and has protected it from erosion.

With the exception of the lava, all the deposits included in this area are composed of unconsolidated materials. The older rocks have not been discovered within its limits. The deepest well is one belonging to the Water Supply Company of Albuquerque, which is 725 feet deep. Through the kindness of the Company, and especially of its manager, Mr. Roderick Stover, we are able to present the section illustrated in Figure 1. This shows the main water belt between fifty and sixty feet below the surface. Although water was obtained at the lowest depth, the supply was so small that the casing was later pierced at higher levels. No indurated rock was met in the boring—nothing harder than cemented sand. This condition leads to the conclusion that before the deposition of these beds, there existed at Albuquerque, a deep trough, either structural or erosional. That it was erosional and caused by a strong through-flowing river seems evident from a study both of the super-imposed beds and the tributary streams of Tijeras Canyon. This stream enters the Rio Grande some four miles below Albuquerque, where it shows but one cycle of erosion, but in its canyon in the Sandia Mountains, we find the conditions represented by the ideal cross-section shown in Figure 2.

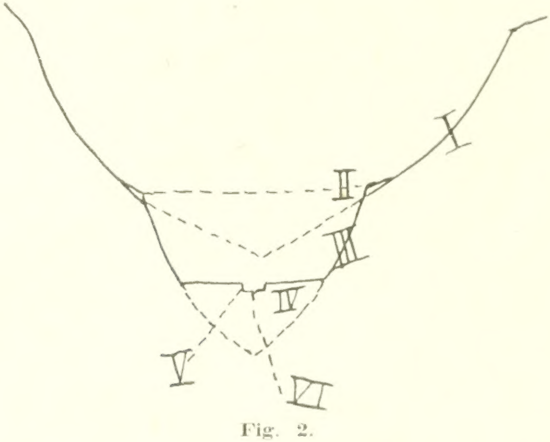

Fig. 2.

The physiography of this stream has been carefully worked out by Dr. W. G. Tight and the matter here presented in relation thereto, is drawn from his unpublished work. We are thus able to give a synopsis of its life history.

I. The outline of the first canyon represents a period of elevation and degradation, during which the major part of the erosion of the mountains took place.

II. The small bench of large water-worn gravel, mainly limestone, represents a period of aggradation and probably subsidence.

III. The outline of the second canyon represents a period of rapid erosion.

IV. The valley filling of fine alluvium represents a period of deposition.

V. The profile of the present channel-way of the stream seems to indicate a rapid and recent cutting of the previous fill.

VI. The present stream bed in gravel shows in some places recent deposition and in other recent cutting.

Using this synopsis of the physiography of a tributary stream, we may turn with some assurance to the more complicated structure of the Rio Grande valley.

Since the Rio Grande is the master stream, Tijeras Canyon should show the same succession of elevations and depressions as the Rio Grande and conversely, with the exception that movements short in their duration may have affected the Rio Grande without affecting its tributary, or local movements may have changed the gradient of the tributary without changing that of the river. Evidence of such local movement should be easily distinguishable at the junction of the deposits of the tributary with those of the master stream. Examinations so far made seem to indicate a continuance of the conditions, prevailing in the canyon, into the valley of the Rio Grande.

Granting that earth movements may have affected the Rio Grande and not the Tijeras stream, unquestionably the main events in its history may be reasonably inferred from those of its tributary.

Reasoning from these considerations and from the known fact that the older valley floor has not been struck at Albuquerque at 725 feet, we may assume that at the time of the first canyon of Tijeras, (Fig. 2), the Rio Grande flowed in a deep gorge in cross-section extending from the Sandias on the east, to the west as far, at least, as the present Rio Puerco. In this valley were deposited, in various stages, the unconsolidated sediments which so effectually conceal its outline.

The bluffs bounding the immediate valley of the river, show a distinct terrace. Just east and north of the Menaul School, and west and south of the village of Atrisco, the terrace, composed of coarse gravels, grading up to cobble stones, lies unconformably on stratified sands, clays and fine gravels, and rests against the same material, which forms the main body of the mesa. North of the Adobe Cliffs on the west of the river, at about the same altitude as the other terraces, is a purely destructional terrace, cut into the clays and silts which form the Loma. These conditions are illustrated by the cross sections of the valley along the lines AB and EF (Figs. 3 and 4).

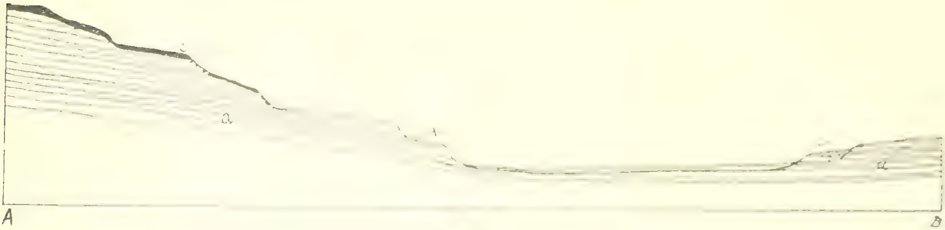

Fig. 3.

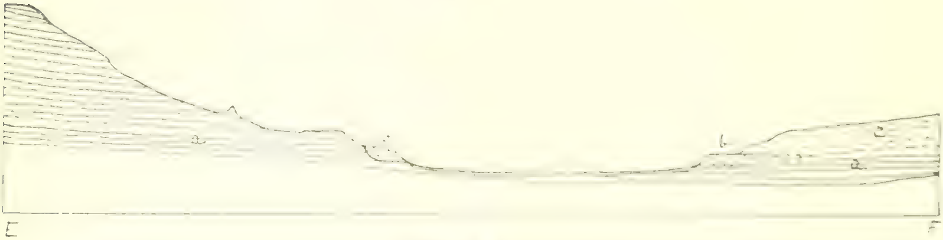

Fig. 4.

"a" is the first fill, called by Herrick "The Rio Grande Loess" and referred to in this paper as "The Rio Grande Beds." "b" is the constructional terrace and the deposit was named by Herrick "The Rio Grande Gravels." The unconformity of these with the Rio Grande beds below, has been uncovered in numerous gravel pits and is easily recognized. That the gravels abut the cut edges of the Rio Grande beds is not so easily demonstrated, but the fact that aerially the dividing line is so distinct and corresponds so exactly throughout its length with the sharp incline that represents the old stream bank, leads naturally to the conclusion that the Rio Grande gravels are the result of a second deposition in a second Rio Grande valley.

This is further supported by the conditions present in the Adobe Cliffs just west of Albuquerque. The river is here enlarging its valley by lateral cuttings and the Loma presents a steep face to the east varying from twenty-five to one hundred and fifty feet in height. In this natural section, lying almost north and south, we find the Rio Grande beds horizontally laid, topped by an unconformity, separating them from sandy clays that are typically side-wash material. This was deposited by small laterals flowing from the west into the Rio Grande. These streams had cut within twenty feet of the present level of the river before they began to fill their beds.

The unconformity might at first seem a small local phenomenon in the bedding of the first valley fill, but its known extent for almost two miles along the valley, the presence of typical local unconformities on the Rio Grande beds, not in any way connected with it, and the difference in character of the river-laid beds below and the side-wash material above, make inevitable the conclusion that it represents a period of cut and fill corresponding to the cut and fill implied by the position and character of the Rio Grande gravels.

The position of the Rio Grande gravels east of Albuquerque between the Menaul School arroyo, and the southern part of the city of Albuquerque, is slightly different from that in other parts of the region. Here the gravels, while unconformable with the Rio Grande beds below, run under the clays of the mesa. However, the mesa materials here differ in character from the Rio Grande beds. These are pure mountain-wash material, all of which is directly traceable to the Sandias. Knowing the comparatively large size of the Tijeras water shed, it is reasonable to suppose that during the second cutting of the valley, this stream excavated a large gorge through the Rio Grande beds into the valley of the river. When the second fill was made and the Rio Grande Gravels deposited, this gorge filled up partly with river material, but largely with mountain-wash. When the deposit of the Rio Grande gravels was completed, the mountain material washed over them and was deposited in a large delta on the river flood plain. Before the third cutting of the valley, however, the river by lateral cutting, removed the most of this over-washed material and left on the east side of the river a destructional terrace similar to that on the west, north of the Adobe Cliffe.

The conditions just described are illustrated in the section CD, Figure 5, in which on the west bank, we have the normal constructional terrace and on the east side, the more complicated constructional-destructional terrace just described.

Following this second deposition, came a period of increased erosion, which excavated the present valley from twenty to fifty feet deeper than the second. In this valley again we have a third recent deposition, varying from a few feet up to as much perhaps, in places, as fifty feet. In no place within this area, however have the recent deposits reached the level of the second valley floor.

One physiographic feature of the valley to be described is the steep incline from the Loma to the Albuquerque mesa and the mesa itself. The material of the mesa is largely the deposit of a great river with large belts of side-wash material whose composition indicates an origin in the west. In the mesa then we have stream and river material, five or six hundred feet above the highest level of the Rio Grande valley. Obviously, these beds must have been deposited from some pre-existing drainage, or else they belong to the Rio Grande beds and have been elevated since their deposition. With the exception of the side-wash material south of the volcanoes, the clay sands and silts of the Albuquerque mesa present no essential differences from the deposits forming the Loma. The presence of arroyo material would be the natural result of their greater nearness to the western rim of the first great valley.

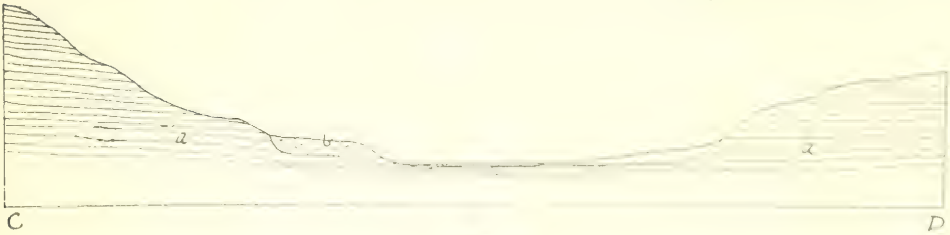

Fig. 5.

If we assume on the basis of the foregoing reasoning, that the Albuquerque mesa is composed of Rio Grande beds, two kinds of movement may be supposed; either faulting took place along the present escarpment of the mesa, or a doming or faulting along an axis further west, which increased the slope of the beds and forced a lateral cutting by the river. Such an elevation and consequent lateral cutting, would produce the present abrupt escarpment to the east.

With regard to the first of the hypotheses, it may be said that no direct evidence of faulting along the escarpment has been discovered. Further objection may be made on the ground of the irregularity of the escarpment which though in the main north and south, presents many irregularities not traceable to recent erosion, nor to any regular cause such as a system of faults.

The second hypothesis is supported by the known fault anticline described by Herrick (Bulletin of the University of New Mexico, Vol. II) as the Isleta Monocline. He describes this as an anticline grading into a fault to the north with the axis of movement running north and south along the Puerco and to the east of the Mesa Pueta. He makes the western side the upthrown block. Recent cursory work in the Puerco valley has shown that, whatever the exact nature of this movement may have been, there is no doubt that the western rim of the Albuquerque Mesa has been elevated at least five hundred feet above and out of relation to the physiography of the Puerco valley. Such an elevation explains the irregularities of the eastern escarpment as due to the varying lateral cutting of the Rio Grande into the rising western half of its flood plain.

What part the Albuquerque volcanoes played in this movement is not readily determined, but it is certain that their eruptions took place immediately after or coincident with the elevation of the mesa. The present outline of the lava seems to be not far back of the extreme limit of flow, while there is no evidence that the lava flowed over the eastern escarpment of the mesa into the bed of the river on the present Loma. This may however have taken place a few miles north, where a small patch of lava occurs on the level of the Loma; it is described by Herrick and its position attributed to slumping, although he suggests that the lava may have flowed over the escarpment.

The volcanos seem to be intimately connected with the elevation of the mesa; for they form a part of a chain of such cones lying on similar mesas north and south along the Rio Grande. They offer another explanation of this elevation since it might be accomplished by intrusive sheets, from the lava vents. However, it has not been possible to find any evidence of such intrusion.

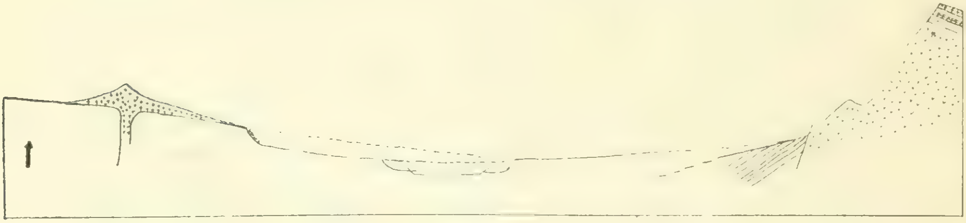

Fig. 6.

Figure 6 is an ideal cross-section of the valley to illustrate the formation of the Loma and the escarpment of the Albuquerque mesa under the most probable hypothesis, the tilting of the western side of the valley by the Rio Puerco anticline.

On the west bank of the river are a series of sand dunes of which four rise above the level of the Loma. The south, middle and north dunes are the largest and rise above their bases about thirty-five feet. The south dune lies directly west of Atrisco and on the gravel terrace while the middle and north dunes lie at a higher elevation on the Loma and between it and the Adobe Cliffs. The fourth dune is about fifteen fieet high and lies on top of the Adobe Cliffs. These dunes have their stoss sides to the west and their major axes almost north and south. The steep lee slopes extend down to the valley floor and in places are encroaching on the cultivated fields. In addition to these dunes are numerous smaller ones, which lie in the lee of the Loma between the south dune and the Adobe Cliffs.

The area of these deposits is indicated on the map and Figure 7 gives the outline and character of the slopes.

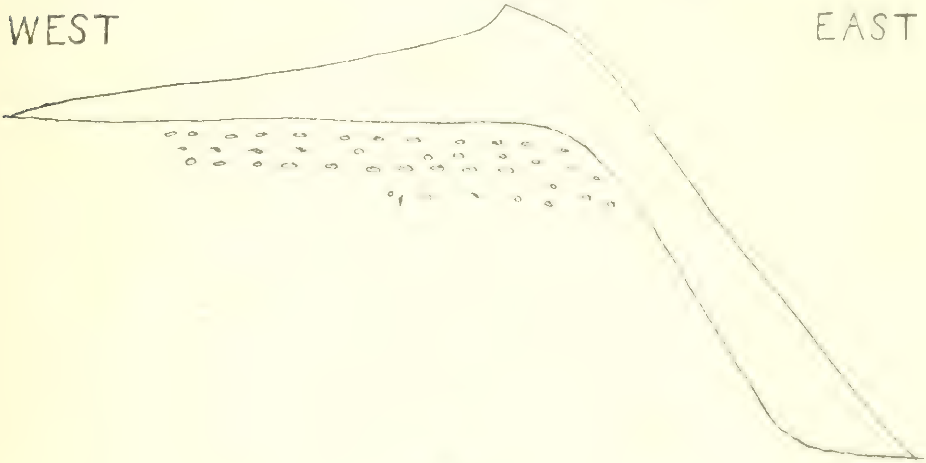

Fig. 7.

From the character of the dunes it is evident that the material is brought in by west and southwest winds, which prevail in this region. The Albuquerque mesa and the Loma offer a ready source of material. In the valley proper, however, the air currents tend to move north and south irrespective of the winds on the mesas. The smoke of Albuquerque is frequently observed moving to the north when the weather vane at the University shows a brisk wind from the west. A fairly strong wind is necessary to disturb this north and south current in the valley. To the natural check in the velocity of the wind due to crossing a wide valley, together with the resistance to the west wind of the pronounced current just described, may be safely attributed these deposits of sand on the edge of the Loma.

The Character and Position of the Beds

The unconsolidated deposits of this area, may be divided into three groups, the deposits of the first valley fill together with the lava flows, those of the second, and those of the present cycle. This division is necessitated not only for physiographic reasons, but also by the character of the deposits themselves.

RIO GRANDE BEDS

Under the name "Rio Grande Beds" will be described the deposits forming the major part of the Sandia Mesa, the Loma, and the Albuquerque Mesa which were deposited as the first fill of the valley. The term "Rio Grande Loess" was applied by Herrick to the portion of these beds exposed underneath the Rio Grande Gravels. The term does not seem applicable for the reason that these stratified silts and sands can hardly be called loess.

The Rio Grande beds outcrop along the Tijeras Canoncito, in the Adobe Cliffs, further south on the western bank of the river near the Hubbell lakes, and along the escarpment of the Albuquerque mesa. They are essentially the deposits of a great river with varying stages. Heavy playa clays are interbedded with sands and gravels. The gravels are well rounded, and in general composed of relatively hard materials.

The deposits of the Sandia mesa contain large quantities of pumice, rounded and water-worn and often cemented into a conglomerate. The clays are often white or greenish and very light in texture. They seem to have been laid down with imbedded particles of pumice which have since suffered considerable decomposition and tend to give the clays a light and porous structure. Along the Canoncito, several exposures show material that is not altogether river-laid. It appears to be out-wash material from the Sandia Mountains rehandled by the river and mixed with strictly up-river clays and gravels. The upper silts and clays are essentially the same material as those exposed under the Rio Grande gravels and which have been described as "loess". Their very distinct stratification and inter-bedding with sands and soft sandstones indicate their river origin, though their even-sized particles and extreme lightness and fineness might suggest a loess.

The beds as exposed on the western bank of the river, consist of heavy red clays and reddish silts interbedded with sands and gravels and pumice conglomerates similar to those in the Sandia mesa. All this material is heavily impregnated with iron and lime. The clays are playa deposits and, though vegetation was probably rather scant, numerous casts of roots and plant stocks are present, composed either of lime or ferric oxide.

While these beds differ from those in the Sandia mesa, in the character of the clays and silts, their position under an unconformity similar to that on the eastern bank of the river, makes their correlation wtih the beds of Sandia mesa a necessity. For while they lie at the same elevation, stratigraphically they are probably lower and have been raised in the movement which formed the Loma. While there is no direct evidence that precisely similar beds occur in the same stratigraphical position on the east side of the river, the section of the Water Supply Company's well at Albuquerque, presents clays and silts which, while leached of their iron, are similar in texture to the beds of the Adobe Cliffs. In the University well below 95 feet similar river gravels and clays are present.

The deposits exposed in the eastern escarpment of the Albuquerque mesa may be divided into two classes: the first pure river material, sands, clays, silts, and gravels, similar to the other Rio Grande beds just described, and the second an angular arroyo material. An exposure of the beds of the first class just east of the most northern volcanic cone presents the two following series within a few feet of each other:

10-20 feet	....Lava.
3 "	....Lava rubble.
1-1½ "	....Whitish sandy clay.
2 "	....Sandy clay.
3 "	....Heavy red clay.

--

15 feet	....Lava.
3 "	....White sandy clay.
15 "	....Yellow sandy clay.
10 "	....Gravel and sand.
5 "	....Interbedded clay and silt
10 "	....Sand and gravel.
15 "	....Fine silts with streaks of red clay.

The gravel in these exposures is well water-worn and composed of quartz, quartzites and ryolites, similar to the gravels of other beds of the group. The silts are fine grained and well laminated. These beds all bear abundant evidence of being the deposits of a large river.

South of the volcanoes are exposed, in the escarpment, the deposits of the second class. These are composed of coarse angular gravels, irregularly interbedded with sandy clays. The whole deposit is unquestionably side-wash material, since its angular character points to a close origin, and its irregular bedding to torrential-stream action. The pebbles are agates, silicified wood, pecular limestones, porphyries, ryolites and andesites. It is very different from the side-wash material to the east of the river, in that, the latter is composed of the erosion products of the Sandia Mountains which are largely archian granites, shists and quartzites, and limestones of the carboniferous age, while the former could have had their origin only in the cretaceous and ryolite-andesite areas to the west.

RIO GRANDE GRAVELS

These lie in parallel lines along the course of the river, in the immediate hills bounding the valley. They were described by Herrick, under this name, in his paper on the Environs of Albuquerque (Bulletin of the University, Vol. I). They lie unconformably on the Rio Grande beds and form the terrace already described.

They are composed of large, well-rounded gravels with lenses of fine, clean sand. The pebbles are beautifully shingled and thus show the southern direction of the flow of the river while forming the second valley. They grade in size from a bird's egg up to large cobble stones, the smaller sizes being relatively infrequent. The greater number maintain a strikingly uniform size with the major axis about four inches and the minor about two and one-half. The material is largely of the hardest quartzite. They were laid down in a stream supplied with abundant material and flowing with a high velocity. Their deposition appears to have been quite rapid for they are very clean and the unconformity below is very distinct and abrupt.

The terrace on the east bank of the river extends from the northern boundary of the area to a point south of Albuquerque where the Powder House Arroyo enters the valley; on the west side from a point just west of Atrisco to the bluffs above the Hubbell Lakes.

UNIVERSITY BEDS

In the side gulches of the second canyon of the river were deposited at the time of the deposition of the Rio Grande gravels, a series of side-wash deposits which are here denominated "The University Beds." They form a considerable part of the Sandia mesa within this area, extending from the Menaul School south to the mouth of the Power House arroyo, and towards the east in a wedge-shape to the eastern limit of the area. They are reddish, sandy clays, frequently cross-bedded, showing many minor unconformities, and containing large angular boulders of Sandia Mountain material. They are without doubt frontal apron wash. The well section at the University shows that they have a depth there of ninety-five feet. As stated previously, these beds were deposited by a lateral from the Sandias during the deposition of the Rio Grande gravels. The cross section of the present canoncito shows but one cycle of erosion; then obviously it could not have been the location of the Tijeras stream at the time of the second cut and fill of the Rio Grande valley; while the mesa to the east of this area, has not been examined to ascertain the former bed of that stream, the large size of the stream in which the University beds were deposited and the excess quantity of material there laid down so as to extend out over the Rio Grande gravels, forces the conclusion that the Tijeras stream which is the only tributary of any size from the Sandias must have made a deep cut over the area around the University during the second cut of the river and there deposited the University beds coincident in time with the Rio Grande gravels.

On the west bank of the river in the Adobe Cliffs, we find a similar deposit lying unconformably upon the Rio Grande beds. This is a sandy clay not well sorted and showing along the contact line that the Rio Grande beds contributed largely to its composition. This was deposited by small tributaries similar to the large tributary on the east of the river and is included under the name University beds.

RECENT DEPOSITS

The recent deposits of the region are located in the flood plain of the Rio Grande and in the cones near the mouths of its laterals. Of these laterals the largest, the Tijeras Canoncito is depositing near its entrance to the Rio Grande, fine red clays. This deposit attains a thickness of about fifteen feet resting conformably upon the eroded Rio Grande beds. The Menaul School Arroyo where it debauches into the valley flood plain is building up a fan cone of angular mountain gravels and sandy clays mixed somewhat with rehandled material from the Rio Grande beds. The numerous small arroyos between the Menaul School and the Cemetery, have built up a miniature frontal apron out of the materials of the terrace and the superimposed University beds forming a slope called by the native people the "Ladera".

On the west bank of the river, between Atrisco and the Hubbell Lakes the same process is taking place, although the slope built up is neither as large nor as steep.

The deposits of the river flood plain are small gravels, fine sands and heavy clays. The demarcation between the recent deposits and the Rio Grande beds below, is not clear and almost impossible of detection. In general it may be said that the recent deposits are more thoroughly leeched of their iron and often contain large quantities of carboneous matter.

Over the cultivated areas the elevation of the land is constantly being raised both by deposition of the silts carried in the irrigating ditches and by a constant accretion of windblown material. The muddy river is as vagarious as the Missouri and is constantly shifting its channel, depositing in one place and cutting in another. The summation of these cuts and fills is difficult to determine, but for the last few years at least the growth in elevation of the cultivated land seems to have kept pace with the river and though occasionally the river cuts in and carries away the fields, it has not made, lately, the wide swings of former times, and it seems probable that, with comparatively small effort, it may be confined to its present channel for an indefinite period.

THE VOLCANOS

The small group of volcanic cones lying on the eastern edge of the Albuquerque mesa, form part of a series of similar effusives extending up and down the Rio Grande for practically its whole course through New Mexico. They are similar in character to the Bernalillo and Isleta volcanos which are situated on either side at distances of about twenty miles.

It comprises three comparatively large cones and two small ones; the largest arising over eight hundred feet above the city of Albuquerque. The southern cone shows a small crater about seventy-five feet in diameter whose eastern wall is broken through in a gap about twenty-five or thirty feet in width; on its northern side is a small lobe about twenty-five feet in diameter whose floor is almost level and composed of scoriacious rubble surrounded by a rim only a foot or two in height and is approximately of the same elevation as the walls of the crater. These are distinctly laminated and have a dip of about thirty-six degrees towards the center.

Evidently just before the last eruption the crater was a seething pot of lava which deposited, by cooling, the laminated walls of the crater in the form of a nest of hollow cones; finally the eastern wall broke through and the crater emptied without, however, disturbing the level of the boiling lava in the northern lobe.

The next cone to the north, presents no particularly interesting features; it seems not to have been in eruption for a longer period than the southern cone; there is no well developed crater and erosion has already begun to destroy its original form.

The third cone is the largest of the group and appears to have a plug similar to the Pelee Needle; it was impossible to visit this cone and study its probably interesting features.

North of this are two very much smaller cones which complete the group of five.

The lava sheet is not very extensive and has its principal development to the east and north of the cones. It seems probable that it did not extend much beyond its present limits. Several places on its present boundary line show the peculiar up-turning and overriding characteristic of the limit of a flow. The eastern escarpment of the Albuquerque mesa, where the capping of lava has protected it from erosion, is covered by a talus of lava blocks. The exposure of the lava itself shows a beautiful prismatic structure. At least three flows are distinguishable and probably there were one or two more. The lava is a black basalt with small felspar phenocrysts. The petrographical characteristics have not been fully determined nor has any work been done towards differentiating the several flows by this means.

THE ALBUQUERQUE MARL AND ITS ORIGIN

One of the most prominent features of the deposits of the valley is the marl bed which caps the mesas. That over the Sandia mesa has been described by Herrick as the Albuquerque Marl, while that on the Albuquerque Mesa he called the Santa Fe Marl. For reasons to be given below it seems best to place both under the one name, Albuquerque Marl.

Herrick's Albuquerque Marl occurs in a bed of mountain wash about ten feet thick capping the Rio Grande beds and lies under eighteen inches to two feet of sandy loam. It varies in thickness, but averages about two and one-half feet. The soft, chalky marl contains pebbles similar to those in the material above and below it. Its boundaries are not sharply differentiated, though the dividing above is much the more distinct.

The marl of Albuquerque mesa is a still more remarkable occurrence for it is from ten to twenty feet thick and more nearly pure calcium carbonate. It lies at the same depth below the surface, but the underlying material is usually more porpus and contains large quantities of decomposing limestone pebbles. On fresh fracture the marl is uniformly white, but where it is exposed to the weather there appear round white blotches in a matrix of darker material, as if the marl was formed by the coalescing of concretionary nodules.

Again on the Loma occurs a marl zone at the same depth below the surface. The percent of calcium carbonate is, however, much lower and the concretionary nature of the deposit much more noticeable. It grades horizontally from a distinct marl into a whitish sandy clay with nodules of lime. North and west of the Adobe Cliffs, where a good sized arroyo has opened an exposure, the marl appears about five feet below the surface and is topped by a recent sandy clay which has a faint whitish stain of calcium carbonate eighteen inches below the surface. This stain, like the marl, has its sharpest bounding line above and fades out more gradually below.

It has been suggested with regard to the origin of the marls of the Sandia and Albuquerque mesas, that they were formed by precipitation, in lakes caused by a damming of the river and made up of waters highly charged with lime. It is assumed that the river was dammed by lava flows to the south at the close of the first fill of the valley, and that the Albuquerque mesa was afterwards elevated. While this hypothesis presents no insurmountable difficulties, it does not explain the marls of the Loma, nor is there, within this area at least, any evidence outside of the marls themselves, of the presence of such a lake. Herrick mentions the probable damming and diversion of the river at Isleta, but the region has not been examined sufficiently to furnish conclusive evidence thereof.

Over the whole of the area except in the immediate flood plain of the river, at a depth of eighteen inches to two feet, we find a whitish calcerous streak varying in thickness from six inches to three feet, and this irrespective of the nature and character of the containing material. In gravels, this may be just a thin film of calcium carbonate over the pebbles, or may form a cementing bond between them; in clays, it varies from faint stain to a considerable percentage of the whole, usually gathered into sub-spherical masses of about one-half inch in diameter.

Mention has been made of the buried marl north of the Adobe Cliffs; we find similar buried zones in the Rio Grande deposits on the east bank of the river. These usually occur in mountain-wash material where presumably there was comparatively little water at the time of their deposition and probably little since. In an exposure of the University beds east of St. Joseph's Sanatorium, there is a buried zone ten feet below the surface of the beds and about two feet below a small local unconformity.

The whitish streak referred to above is clearly seen in this exposure about eighteen inches from the present surface of the ground and extends throughout the whole extent of the University beds; towards the south where the beds abut upon the Rio Grande beds of the Powder House Ridge, the talus from the ridge covers a portion of the University beds, but this whitish streak maintains its distance from the surface and so extends up the slope until it joins the Albuquerque Marls lying upon the Rio Grande beds; the junction of the two is not distinct and sharp, but one grades into the other.

In an arid region where the run off is not sufficient to leach out all the soluble salts, there is a tendency for them to concentrate by one process or another. Just as the "alkalais" concentrate at or near the surface of the ground by capillarity from below and leaching from above, so also calcium carbonate concentrates in the same manner; that is, as the surface of the soil dries, capillarity tends to restore to the soil a uniform moisture, by raising moisture from the water table below. If the water contains salts they are deposited by evaporation at the surface. Every rainfall, however, re-dissolves them and carries them down. Between these two forces, there is effected a balance and at some plane below the surface where precipitation of the material takes place which in time forms a zone; for all the material carried above this zone by capillarity, is leached down by rainfall and the material carried below it by rainfall is carried back again by capillarity. The position of this zone for different salts will vary according to their solubility or chemical characteristics. The quantity of material in any zone is a function of the time involved and the supply of material, provided that the climatic conditions, and therefore the balance between precipitation and evaporation remains constant.

That the processes just described are capable of forming the large marl deposits found in this area, is suggested by C. W. Dorsey in speaking of the formation of "alkalais" below the surface by capillarity and evaporation. (Alkalai soils of the United States, Bureau of Soils, Bulletin 35, page 11.)

To have formed the heavy marls of the Albuquerque and Sandia mesas, by this method, it is necessary that the climate should have been arid, since the time of the first fill of the valley. The Rio Grande beds bear evidence in themselves of arid conditions during the time of this fill, for they contain large quantities of unleached iron and lime and few evidences of vegetation and, as has been mentioned before, they contain a small local concentration zone, buried at least fifty feet below their highest level. During the time of the second cutting of the valley we have no evidence regarding the climate, but at the time of the second fill, arid conditions must have prevailed for the University beds are essentially an arid region deposit; that is, they are composed of frontal-apron material. We have already noted the occurrence of a faint concentration zone quite deep in these beds. During the time of the third cutting of the valley, we have no evidence to indicate the climate. But if it had varied to any considerable degree towards greater himidity, evidence of the ensuing vigorous plant growth would unquestionably have remained until today. Then we have every reason to believe that conditions of climate have been comparatively constant with no large variation, thus affording continuously favorable conditions for the concentration of marl deposits.

Those portions of the area whose surface has been continuously undisturbed for the longest period, have consequently the heaviest concentration zones. These are those portions of the Sandia Mesa formed by the Rio Grande beds and the Albuquerque mesa. Over these areas the concentration zone is so heavy as to be called a marl and has already been described as such. The marl on the Albuquerque mesa is from three to five times as thick and usually more pure than that on the Sandia Mesa; this seems to be due, not to greater time in deposition, but to the large number of limestone pebbles in the beds below. These are usually in the first fifteen or twenty feet below the marl, in a highly decomposed condition and form a ready supply of material for the formation of the marl. In the Sandia mesa such quantities of limestones are not present and the lime seems to be drawn largely from the pumice conglomerates which here form no inconsiderable part of the Rio Grande beds. In these extremely heavy concentration zones, the compartive purity of the material and its freedom from included materials, suggests that as the lime was precipitated in the zone, there was a tendency for other materials to move out; that is to say, that metasomatism had taken place to a greater or less degree.

The following analysis of a sample of marl from the Albuquerque Mesa about one-half mile south of the volcanos, was made by Mr. J. W .Miller, '12, Chemical Department of the University:

Silica	38.04
Calcium oxide	33.77
Alumina and iron oxides	8.52
Water free and combined	11.52
Magnesium oxide	.77
Sodium and Potassium	Traces

The concentration zones of the Loma and of the University beds are in process of change towards marls similar to those just described. The zones of the Rio Grande gravels and of the side slopes of the region, though working against the odds of scanty material or loss from erosion, are constantly increasing towards the concentration attained on the Loma. Nor is the process at a standstill in the marls of the Albuquerque and the Sandia mesas for they are being constantly increased in thickness and purity.

TIME RELATIONS

With regard to the age of the deposits of the valley, they present no direct evidence in themselves, for plant and animal remains are practically absent. The only fossils yet discovered are those of small unidentified fresh water gasterpods from the Rio Grande beds of the Adobe Cliffs. However, the first filling of the valley took place subsequent to the elevation of the Sandia Mountains which are certainly post-cretaceous. Herrick notes that the Rio Grande beds of the Albuquerque mesa where exposed in the Rio Puerco valley, rest unconformably on the Cretaceous and he assigns them to the Eocene. Dr. Douglas W. Johnson (Geology of the Cerillos Hills, N. M. School of Mines Quarterly, Columbia University, 1903-4) described a series of unconsolidated sediments on the Gallisteo Creek, a tributary of the Rio Grande and assigns them to the Santa Fe Marls originally described by Hayden (Preliminary Field Report, U. S. Geological Survey, Colorado and New Mexico, pages 66 to 68, 1869).

Johnson gives a summation of the authorities regarding the age of these marls and places it as from the late middle Miocene to the present time. After saying that they rest unconformably on beds of Laramie age and speaking of the erosion period between, he says, "It is not unreasonable to suppose that this erosion period dated back to or near the close of Laramie time, the great upheaval which tilted and elevated these beds being the same which inaugurated Tertiary conditions." Now, this upheaval was the movement which raised the Sandia Mountains and for this reason, as well as for the fact that the Galisteo is a tributary of the Rio Grande, the Cerrillos sequence is comparable to the Tijeras and the Rio Grande sequence. We know further, from the unpublished work of Dr. Tight, that the Rio Grande gravels extend up the Galesteo Creek and form part of the group described there as Santa Fe marls. We may then, pending the discovery of paleontological evidence, assign the deposits of the first fill of this valley to a period beginning with the late middle Miocene.

With regard to the Rio Grande gravels, direct evidence is still more lacking. Herrick assigns them to the Quaternary, suggesting that the deposit was a gravel train from the glaciated regions of Colorado. Certainly the unconformity between the gravels and the Rio Grande beds represents a considerable intervals of time and it is not unreasonable to assume that this degradation and agradation in the Rio Grande valley is connected with the world-wide changes of the Quaternary.

ECONOMIC GEOLOGY

The clays and gravels of the Rio Grande valley are of considerable importance economically, at least from a local standpoint. The gravel of the Rio Grande gravels has been extensively used for the making of concrete in the city of Albuquerque and for railroad ballast; the sand of the same deposit is used for plastering and also in locomotive sand tanks.

The sandy clays of the University beds and the recent flood plain deposits supply the common brick of the vicinity; this is usually mixed wet and burnt in an up-draft kiln; the product is porous and friable and has no great crushing strength. The Albuquerque Brick Company is working a recent deposit of comparatively large size with a dry pressed process and an updraft kiln. The clays of the Rio Grande beds have never been used although they appear to be exceptionally adapted for the making of brick and tile. It is understood, however that they furnish a good quality of moulding sand which has been used with success in the local foundry. In making the streets of Albuquerque, a base of gravel from the Rio Grande gravels is capped with about twelve inches of mixed clay and gravel from the University beds. The gravel is taken from shallow pits and is composed largely of limestone pebbles. The clay is from the same formation and is mixed with the gravel by hand. When the whole is rolled in the roadway, the limestone pebbles are crushed and broken and together with the lime from the concentration zone form a good binder and make a road almost as good as macadam.